Evaluating Electrical Resistivity as a Procedure to Aid in Characterizing Subsurface Conditions Measurements in State DOTs

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16. **Abstract**

The Iowa DOT Soils Design section participated in the Demonstration Stage of the Advanced Geotechnical Exploration Methods (A-GaME) initiative. The A-GaME initiative sought to promote the use of advanced geotechnical methods as a means to reduce cost in subsurface investigation. One of the proven geophysical methods promoted is known as Electrical Resistivity (ER). In response to the A-Game Initiative, the IDOT Soils Design Section has investigated electrical resistivity (ER) as a novel technique to aid with subsurface investigation.

Soils Design proposed to apply ER to evaluate if the technology could result in: (1) a reduced number of borings, (2) an enhanced understanding of subsurface conditions and site variability, (3) identification of depth to bedrock, and (4) overall reduction in geotechnical subsurface investigation costs.

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Evaluating Electrical Resistivity as a Procedure to Aid in Characterizing Subsurface Conditions

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INTRODUCTION

The Iowa DOT Soils Design section participated in the Demonstration Stage of the Advanced Geotechnical Exploration Methods (A-GaME) initiative. The A-GaME initiative sought to promote the use of advanced geotechnical methods as a means to reduce cost in subsurface investigation. One of the proven geophysical methods promoted is known as Electrical Resistivity (ER). In response to the A-Game Initiative, the IDOT Soils Design Section has investigated electrical resistivity (ER) as a novel technique to aid with subsurface investigations.

ER technology utilizes an instrument that directs an electric current into the subsurface and measures the resistivity of the ground layers beneath. The system is paired with a software that uses the measured resistivity data to produce models of the subsurface. The models provide interpretation of various soil and rock layer properties. Generally, materials that are more resistive or less conductive are typically less dense, have higher porosity, and do not hold moisture well. Alternately, less resistive and more conductive materials are denser and hold more moisture.

Currently at Iowa DOT, subsurface geotechnical analysis is interpreted by performing costly soil borings that only provide data for the exact location they were obtained. Extrapolating data away from a boring is risky as conditions will vary with distance from the boring. In many cases borings are not taken in optimal locations as little is known of the subsurface until after borings are evaluated. In contrast, the current produced by ER can cover hundreds of feet, providing a greater area of interpretation at less expense. By performing an ER survey, a preliminary interpretation of the ground beneath would be gained, and the variability of the area would be better understood. Pairing an ER survey with initial borings for ground truthing would potentially allow for better determination of future boring locations containing the most critical data.

Soils Design proposed to apply ER to evaluate if the technology could result in: (1) a reduced number of borings, (2) an enhanced understanding of subsurface conditions and site variability, (3) identification of depth to bedrock, and (4) overall reduction in geotechnical subsurface investigation costs.

CASE STUDY

A pilot project was chosen in Mahaska County on US 63 where the roadway had been built above abandoned underground coal mines. Iowa is known to have over 300 abandoned mines, most of which are old coal mines from the mid to late 1800s, Figure 1. Several mines are identified near or directly beneath the area of interest on US 63 between Oskaloosa and Eddyville, Figure 2.

The ER investigation was triggered due to surface activity that took place from 2020 to 2021, Figure 3. In August of 2020, STA 1345+00 to 1344+00 in the southbound lane experienced subsidence in the range of 1-3 inches. In March of 2021 a suspected sinkhole six foot in diameter appeared near the southbound lane shoulder, and five months later in September of 2021, another subsidence occurred on the northbound lane at STA 1353+00 to 1355+00, Figure 4.

Several coal mines were identified in the area and suspected to be related to the referenced surface activity. Figure 5 shows maps of underground room and pillar mines in orange and surface or strip mines in blue. Consolidation Coal Mine #2 was found to be directly beneath or near the two subsidence locations, and Ellis Mine was mapped below the 2021 sinkhole that was suspected to be a mine shaft. Both are room and pillar mines (a sketch of a working room and pillar mine is shown in Figure 6). In such mines the coal is mined away while leaving a portion to act as pillars or structural support. It was suspected the old abandoned underground mines beneath the roadway had experienced a collapse leading to the surface subsidence. Additionally, the 2021 sinkhole was thought to be a mine shaft that had opened to the ground surface as it was the appropriate diameter and had a definite circular shape. Unfortunately, the location of the hole did not correlate to the mine shafts mapped by the Iowa Department of Natural Resource (IDNR). It is possible that the mapped locations are incorrect, or there could be unmapped areas of the mines that are not recorded. Regardless, the circular shape, size, and known mine activity in the area strongly suggest the feature could be caused by an old mine shaft.

Due to the challenging nature of the site, ER was thought to be a helpful tool to help characterize the subsurface and assist in the investigation of the area. Before Soils Design acquired the ER unit, the Iowa Geological Survey (IGS) was contracted to perform an ER survey of the suspected mine shaft over Ellis Mine. The void had been filled with aggregate for stabilization and when ER was performed by IGS no other voids were identified by the IGS. Once IDOT Soils Design acquired an ER unit through the EDC-5 Initiative, an ER survey of the Consolidation Coal Mine #2 area was conducted. As part of the initiative Soils Design wanted to apply ER to assist with planning boring locations, provide a greater interpretation of the subsurface, identify depth to coal/bedrock and possible voids, and reduce potential remediation and design costs.

METHODS

A total of 9 electrical resistivity survey lines were taken at the US 63 roadway project. Starting and ending points of each line were identified by using a Juniper Mesa sub-meter precision GPS unit. The lines were distinguished based on their locations relative to the northbound lane, southbound lane, and median, as well as their positions running North to South, Figure 6. For example, the survey line on the northbound lane, furthest to the North would have been NB.1.

Stakes and electrode cables were placed at the survey lines with a spacing of 13 ft, Figure 7A. At this electrode spacing, subsurface anomalies as small as 6.5 ft. could be distinguished. Based on the length of the lines, data would be collected at a depth of 200 ft. Before the surveys, each line was walked to identify visible features that may affect the survey data. No features were seen that would have caused anomalous readings. However, precipitation experienced during some surveys could have introduced noise to the data.

A Super Sting Electrical Resistivity geophysical unit from Advanced Geosciences Inc., Figure 7B, was then run on each line. The collected data were processed by inversion in the Advanced Geosciences, Inc. program EarthImager 2D. To account for field topography, terrain files were created by capturing elevations at the electrodes with LiDAR maps and applied to the survey data. The resulting models were analyzed to locate potential anomalies and features indicative of subsurface voids and mine workings. Any identified anomalies and features were marked for emphasis.

RESULTS

ER models for the southbound lane, median, and northbound lane are shown in Figures 8, 9, and 10 respectively. Each model shows elevation in feet (x-axis), and distance from the starting point in feet (y-axis). ER measures the resistivity of the subsurface material encountered as Ohm-m. A scale bar is provided for each model on the right side of each model. Generally, bedrock, coal, and well lithified material would be less resistive or warmer in color, yielding red and orange colors. A more loose, less dense, and relatively moist material, such as soils and fill will be conductive and therefore cool in color, such as blue.

Moving from the north to the south, a layer of fill over weathered shale, clayey shale, or siltstone was seen. These are reflected in the cooler colors, blue and green. In the northern portion at deeper depths resistive warm colors representing coal or bedrock were measured. Moving southward a topographic decline is observed and the coal/bedrock appears to pinch out. This trend would seem to agree with the Iowa DNR maps that move from subsurface to surface mining, suggesting that coal resources were available at the surface when moving to the south.

DISCUSSION AND CONCLUSIONS

Where the southbound lane subsidence occurred, bores were taken prior to the ER survey, making an excellent opportunity to correlate them with the ER model data. These borings are labeled 1-5 and shown in pink on the southbound 2 model of Figure 8. A fence diagram of the borings is seen in Figure 11. When comparing the models to the borings and subsidence locations, several areas of suspected risk were identified as the borings taken in the southbound model 2 area coincide with the location of the southbound subsidence noted in Figure 5. A significant “suspected risk” zone is visualized in the southbound 2 model at the location labeled with the letter V. This area of the model suggests that the less resistive green areas could be indicative of a collapse of material in the subsurface. This is further supported with the Figure 11 fence diagram as boring B-4 indicates a “possible void.”

The borings also correlated well with conductive areas of fill; these were identified in the upper layers of the model in blue and were seen in the material collected from the borings. Further agreement was seen at depth, where shale and coal were described at deeper depths. Overall, the ER surveys helped determine the approximate depths to the bedrock and coal. They also helped identify areas of contrast between units that could be high risk. A good correlation was seen when moving down in elevation. Soils Design did find it difficult to conclusively interpret locations were voids or mine collapse may have occurred, but the models helped direct broad areas of concern though the contrasting resistivity data.

CURRENT AND FUTURE USE

Since the ER survey on US 63 between Oskaloosa and Eddyville has been performed, the Iowa DOT Soils Design section has gone on to conduct surveys of different scenarios including a landslide and the location of a prospective bridge. In the future, Soils Design plans to use the ER equipment to continue to monitor the US 63 site, as well as other remediated road sections that had previously experienced subsidence.

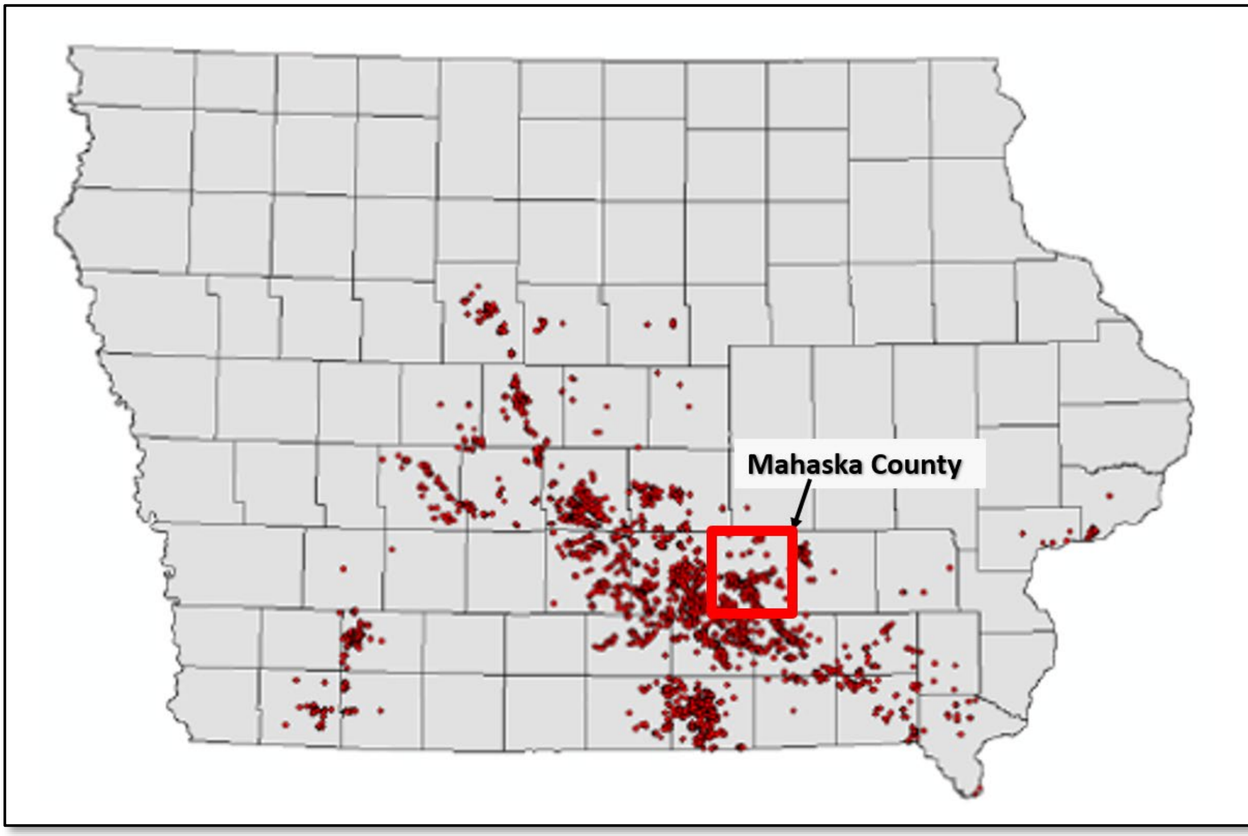

Figure 1: State of Iowa with known coal mine locations from Iowa Department of Natural Resources. Mahaska is highlighted in red.

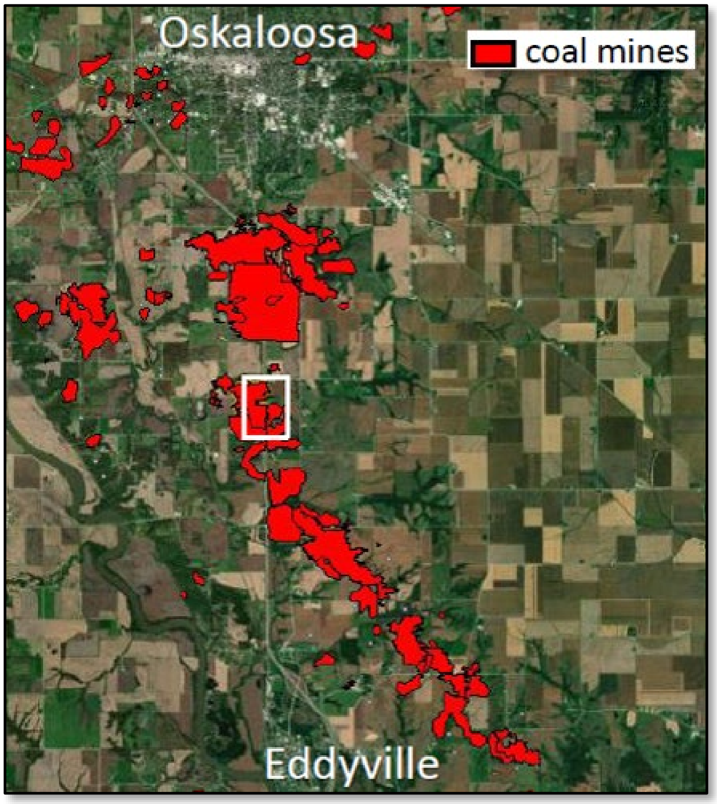

Figure 2: Area of Interest showing US 63 with Oskaloosa and Eddyville locations and known coal mine locations in red.

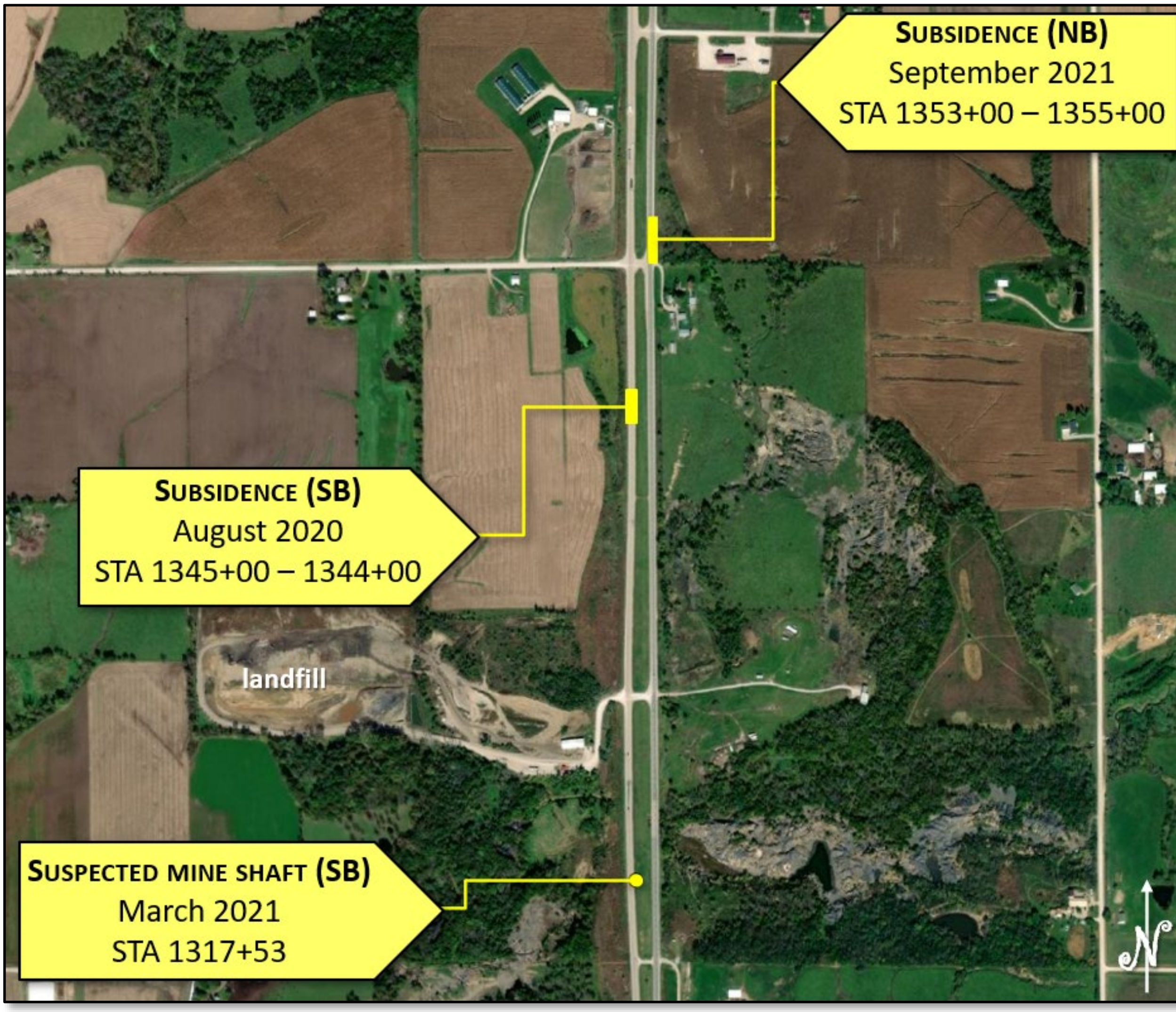

Figure 3: Location of subsidence and suspected mine shaft on US 63.

Figure 4: a- Suspected mine shaft opening on US 63 south bound near shoulder, March 2021.

Figure 4: b- Subsidence on US 63 north bound, September 2021.

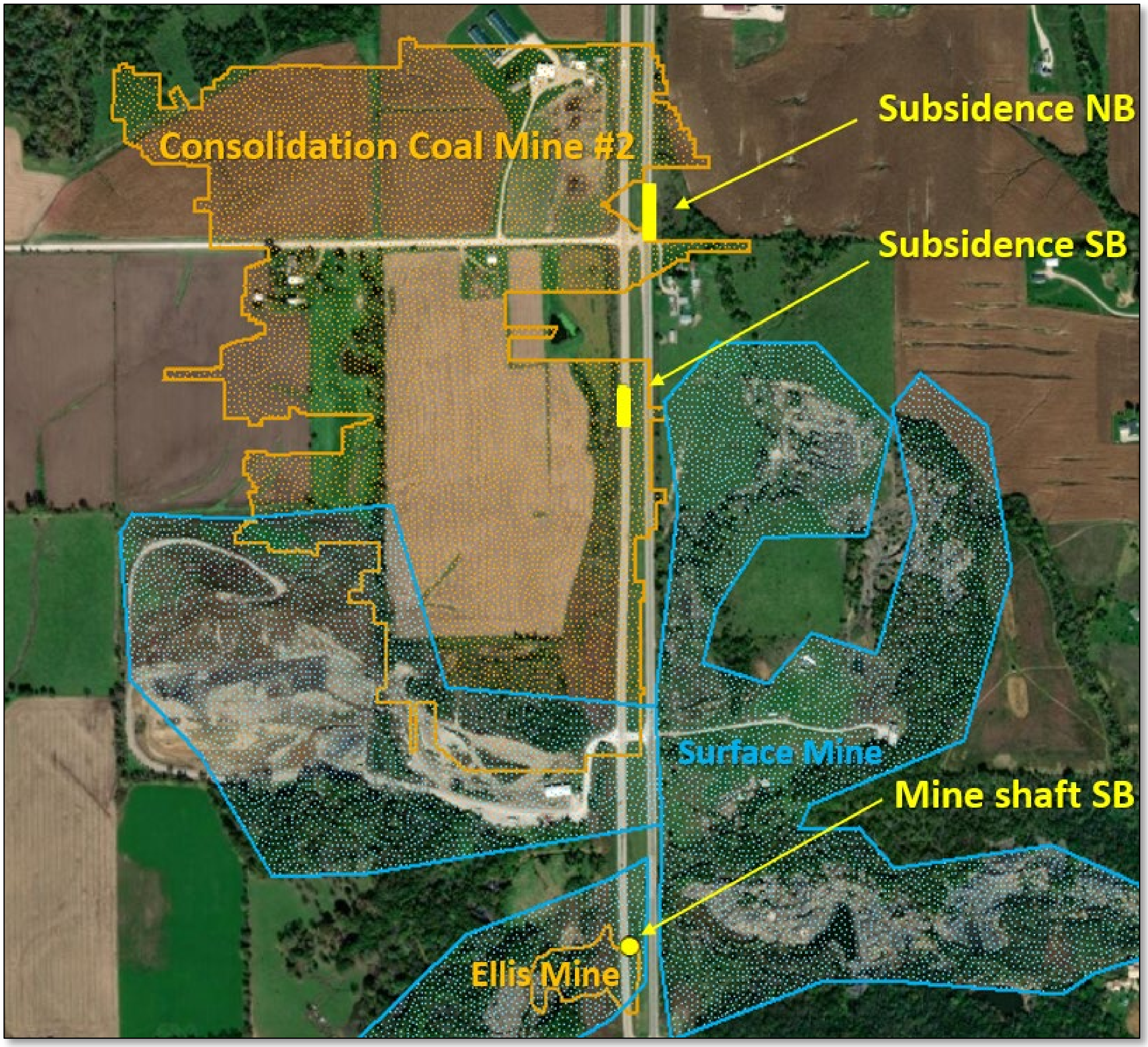

Figure 5: IDNR mapped coal mines are shown in relation to US 64. Subsidence and mine shaft locations are shown in yellow.

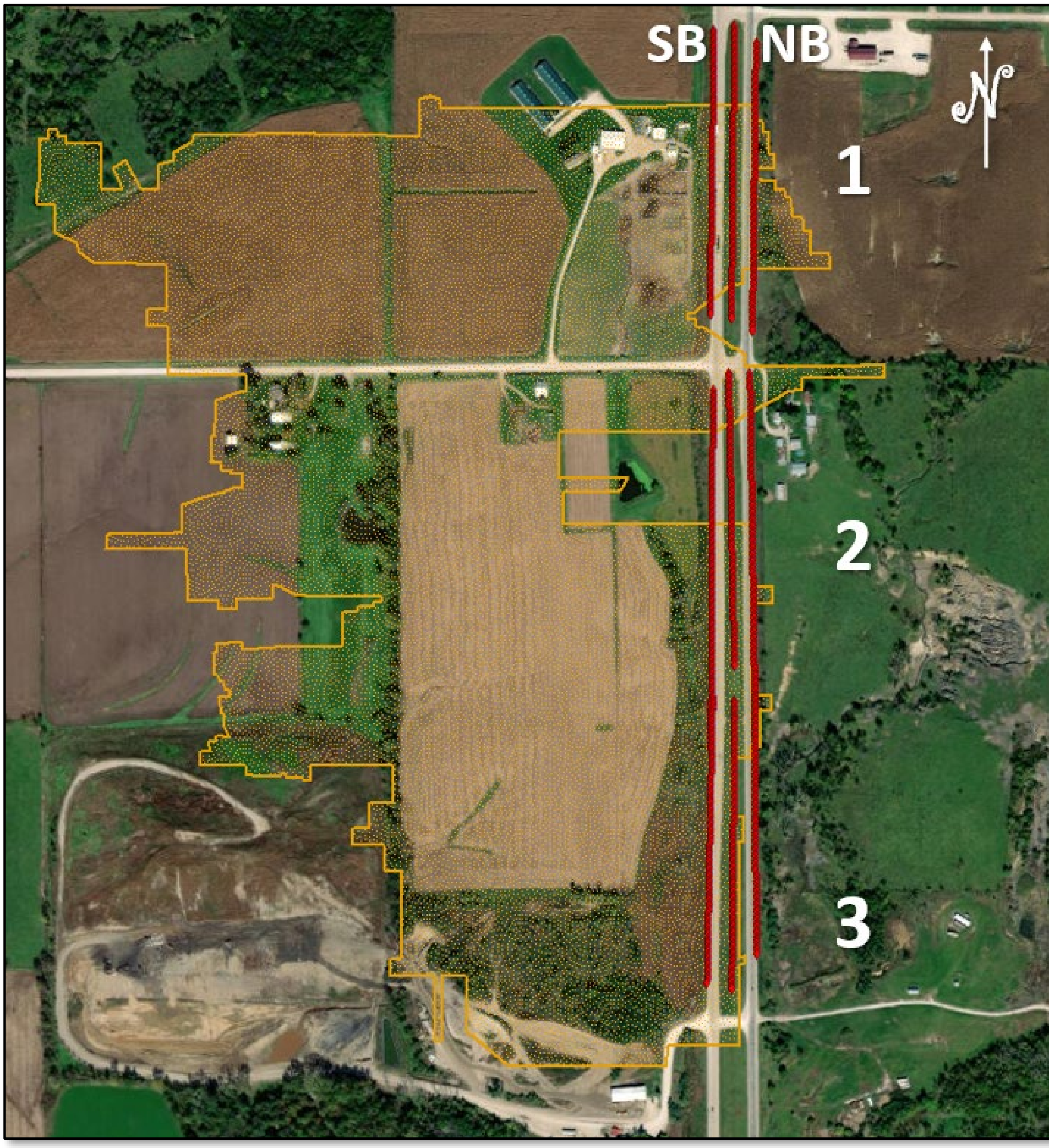

Figure 6: Location of 9 ER survey lines shown with red points. Each point represents the location of an electrode.

*Figure 7: **A.** View of ER survey line showing location near US 63 and electrode spacing of 13 feet between each electrode. A close-up view of a single electrode is shown in the lower left corner. **B.** AGI Super Sting unit, the set up was transported in a field cart.*

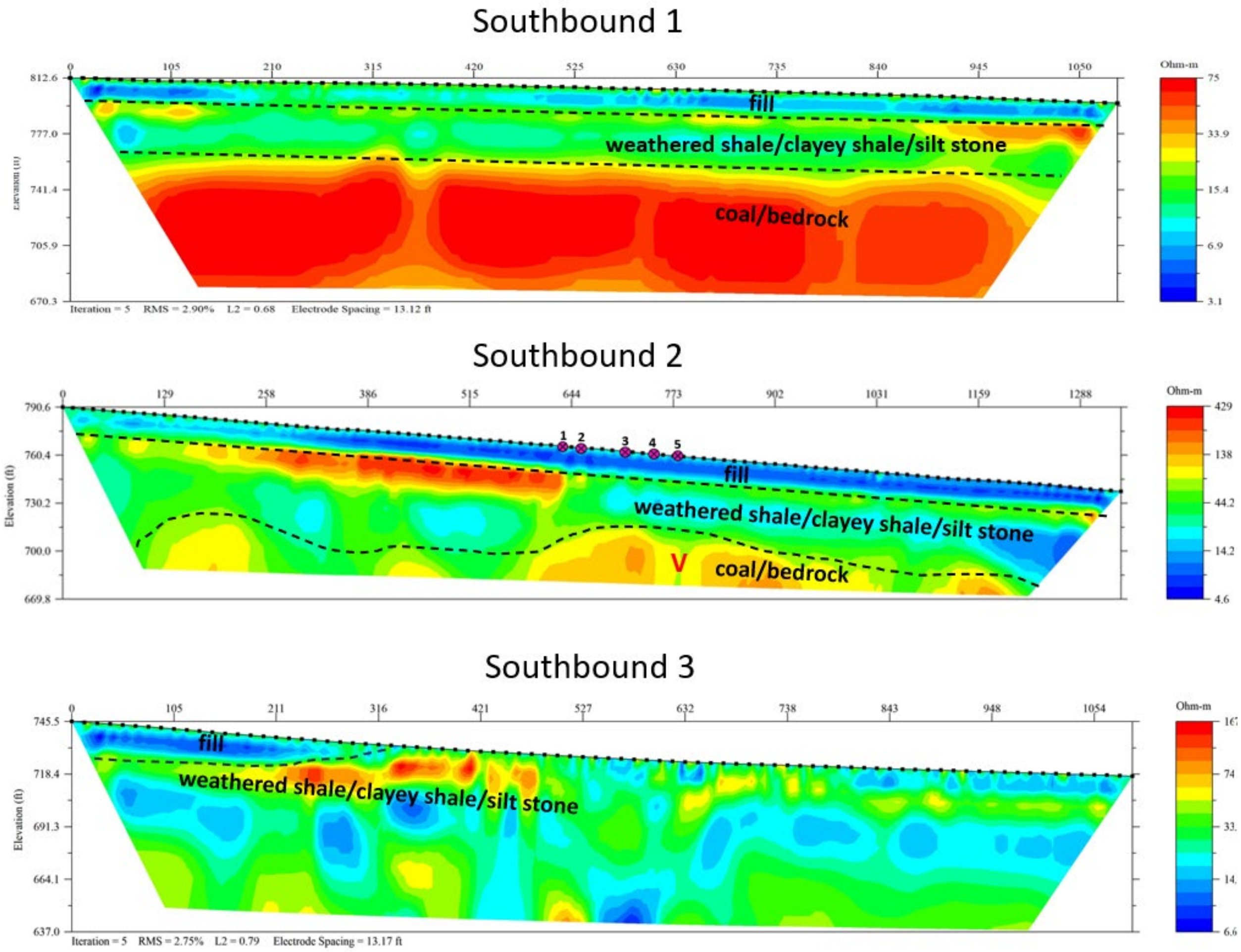

Figure 8: ER models from US 63 southbound lane. Arial view can be seen in Figure 6.

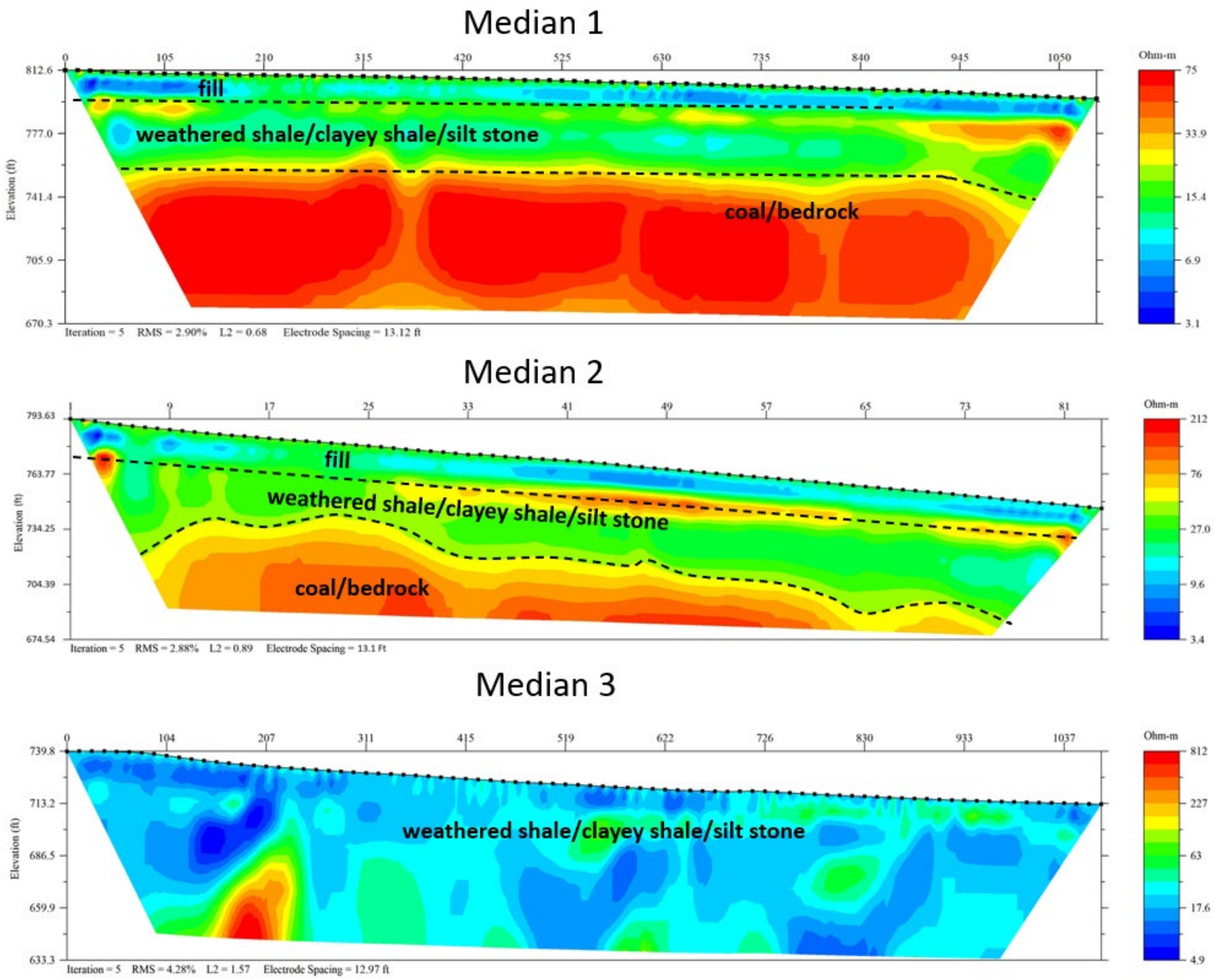

Figure 9: ER models from US 63 median lane. Arial view can be seen in Figure 6.

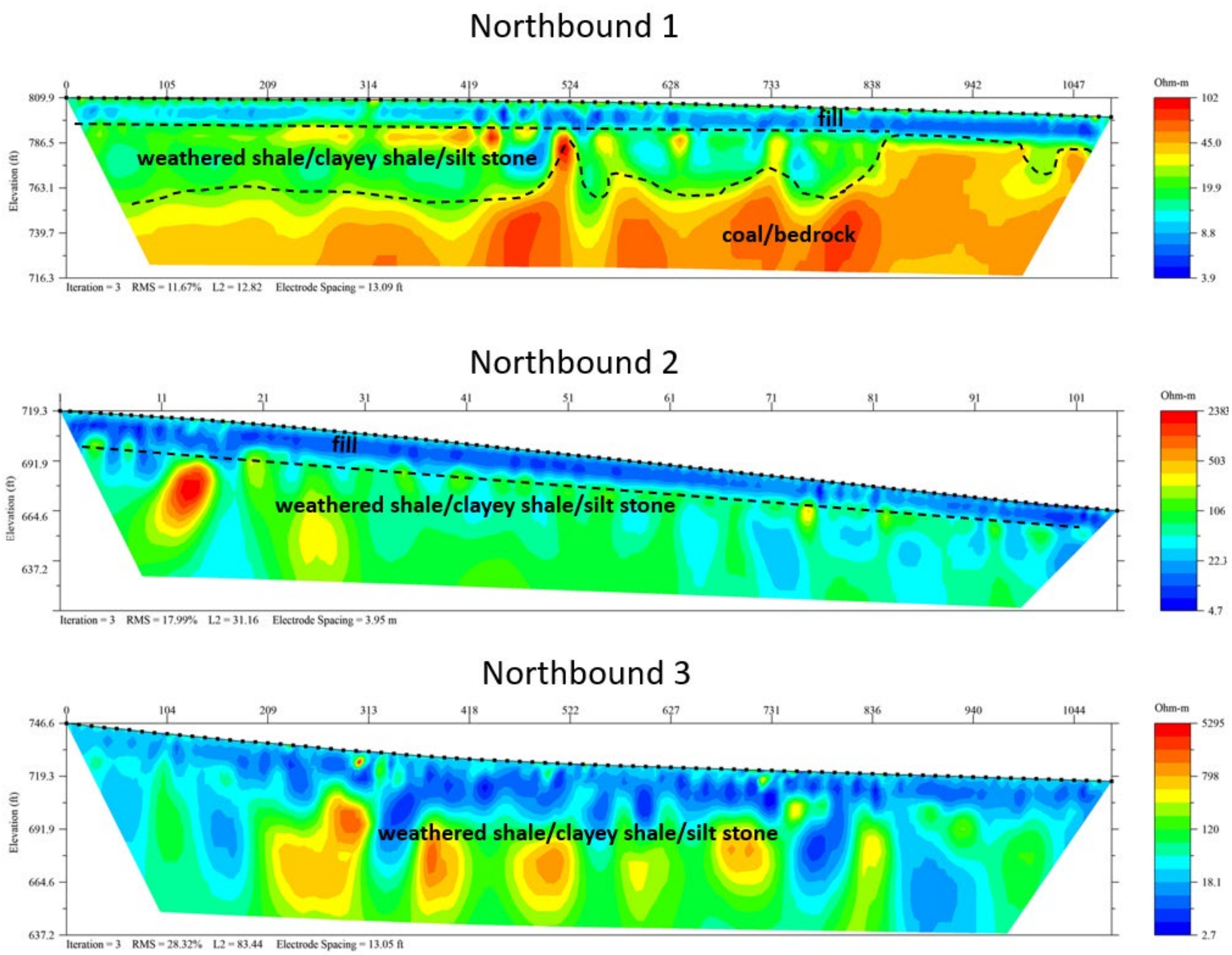

Figure 10: ER models from US 63 northbound lane. Arial view can be seen in Figure 6.

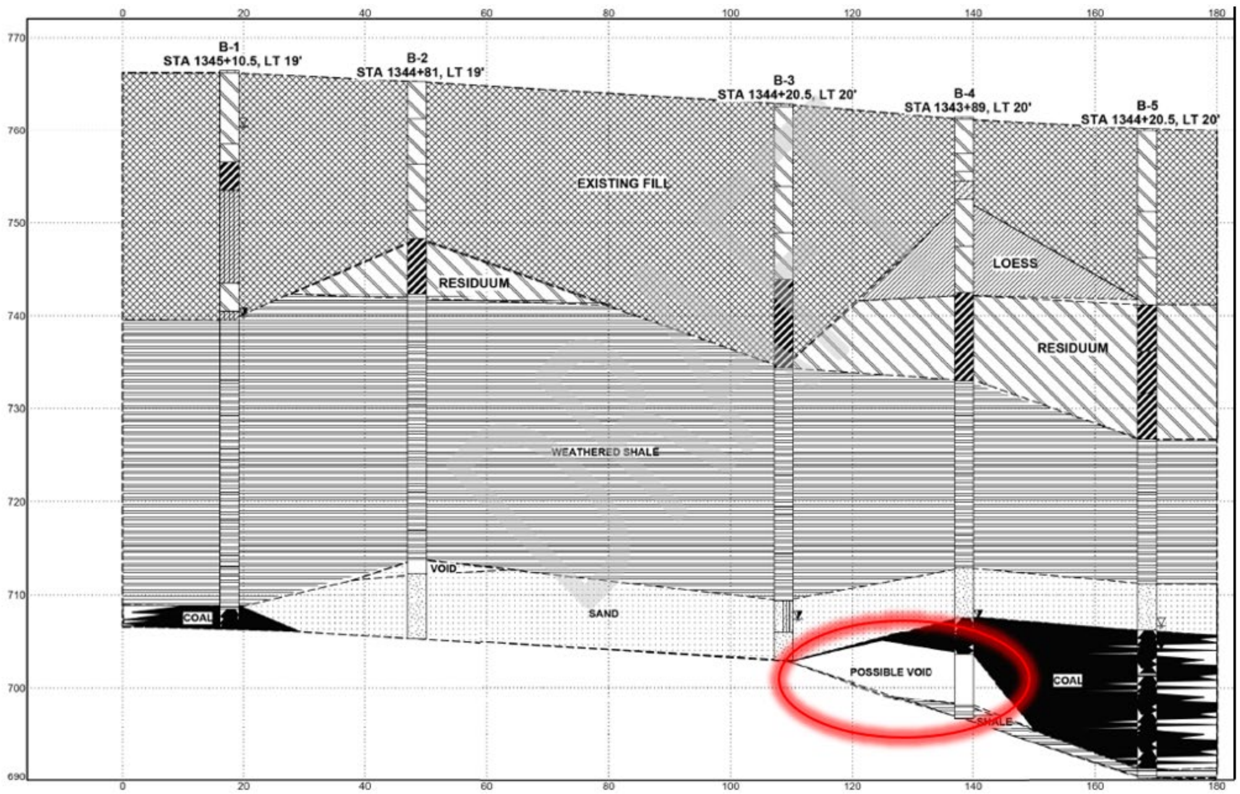

Figure 11: Fence diagram of borings taken from southbound lane.